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SUGGESTED NEW DESIGN FOR LOCOMOTIVE BOILERS IN CHINA

Chi-hsieh Kung-ch'eng Hsueh-pao
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Ch'eng Hsiao-kang

The design of locomotives boilers has been evolving for a number of years. Boilers are an important factor in a mobile motive power plant that is powerful and reasonably efficient. However, when the usual designs are carefully studied, a number of irrational features are found. If these can be remedied by improvements in design, the horsepower and efficiency of boilers can be increased, and further economy in fuel consumption can be attained.

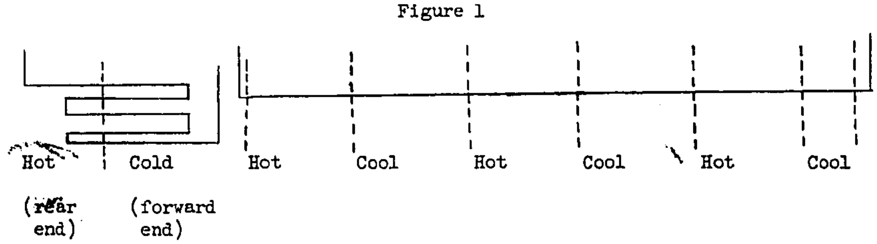
A. Superheater

A superheater is generally composed of a number of pipe units inserted in the large fire tubes. Each unit consists of four or more lengths of pipes joined into a single unit by machine-forged return bends, thus providing for four (or more) passes of steam in each tube. The ends of these pipes are connected with the main header in the smokebox. When the hot gases pass through the fire tubes, the saturated steam in the superheater pipes absorbs some of the heat and becomes superheated. The effect of this is to reduce or eliminate condensation when steam is admitted to the cylinders, and to increase the locomotive's effectiveness by about 25 percent. The use of superheaters is rational, but the usual method of design and application of superheaters is not very rational, as can be seen by noting the following points.

1. The temperature in the fire tubes is about 1,000 degrees centigrade at the ends near the firebox and only about 400 degrees centigrade at the opposite ends, and the temperature of the superheated steam in the pipes is only about 300 degrees centigrade. Consequently, the rear ends of the superheater pipes, and particularly the forged return bends, are frequently burned out.

2. With the superheater pipe units being placed in the fire tubes, with one end hot and the other end relatively cool, the temperature in the sections of the pipe are as indicated as in Figure 1, left portion:

Figure 1



Now suppose the unit pipes are straightened out into one straight line as in the right portion of Figure 1; it can then be seen that the temperatures in the different sections of the pipe units are alternately high and low.

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No designer would deliberately plan to have the steam alternately heated and cooled in the course of its passage through the superheater pipes; yet that is exactly the case in the usual design of superheaters. It is only because the pipes are bent up in the tubes out of sight and touch that this is not always realized.

3. The larger the diameter of the fire tubes, the smaller the total heating surface of the boilers; and since superheaters of the older type require large fire tubes, the installation of such superheater pipes diminishes the total heating surface of the boiler.

4. Any heat-exchanging device ought to use the counterflow principle in order to attain the greatest efficiency. This means that the flow of heat should be from A to B, and of cold from B to A. But in the design of most superheaters, this principle has been violated, for the steam in its passage through the superheater pipes moves alternately from cool to hot sections. Naturally, this diminishes the efficiency of heat transfer.

5. In principle, the smokebox should not be very hot; in fact its temperature should be as close as possible to that of saturated steam. But since the main header carrying the superheated steam is located in the smokebox, the temperature of the smokebox is raised by about 150 degrees centigrade nearly to that of the superheated steam, and a great amount of heat is thus lost up the stack. Such loss reduces the heat efficiency of the boiler.

6. The obstruction of the fire tubes by the superheater pipes impedes the circulation of the gases and interferes with the draft.

Since these six features reduce the effectiveness of the superheater and the efficiency of the boiler, we must eliminate certain design defects if we wish to get the full benefit of the superheater. The present problem doubtlessly arises because locomotives originally had no superheaters and they were added later without suitable changes in design of the boiler as a whole. Since superheaters are now regarded as indispensable, fresh consideration should be given to redesign of the whole boiler.

B. Main Features of a New Design

Since the design and location of the old types of superheater are not rational, where should it be placed? Let us consider this question from the standpoint of the temperature of the burning gases. This temperature reaches its peak in the firebox, and then as the gases move to the front end of the locomotive, their heat is absorbed by the water surrounding the fire tubes, and their temperature gradually decreases. Since the superheater pipes are easily damaged by overheating, it is best not to place the superheater at the extreme rear end of the boiler. Also, since the temperature of the gases on leaving the smokebox should be as low as practical, and the superheater is comparatively hot, it is inadvisable to place the superheater too near the front end of the boiler. Thus, the only suitable place for it is in the middle-section of the boiler, as similarly installed in stationary boilers.

Most locomotive boilers are built as an integrated whole, with the fire tubes running straight from the rear end to the front end of the locomotive. If the superheater is placed in a middle position, the boiler must have two sections. Is this arrangement rational? I believe it advisable to adopt this arrangement because, besides solving the problem of the superheater, it has other advantages. These are as follows.

1. To avoid the harm caused by vibration, designers should avoid making fire tubes more than 7 meters long. If the fire tubes are in two sections, the problem of excessive length is avoided.

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2. With the fire tubes being short and vibration much reduced, the tubes could be made thinner, which would be more favorable for the conduction of heat. Also, the material in the pipes would weigh less and hence cost less.

3. Large fire flues should be avoided and small fire tubes could be made smaller, so that there could be more of them, thus enlarging the heating surface and increasing the boiler's steaming capacity.

4. Since the superheater is to be placed in the middle section of the boiler, it should be a compact unit, rather than long and extended. Such a unit would be much more convenient to build, install, inspect, and repair.

The four advantages just mentioned, while incidental, are nevertheless important. Considered together with the six disadvantages of the old design of superheaters, all of which may be overcome by designing the superheater so that it can be placed in the middle section of the boiler, they constitute very good reasons for a new design.

However, the new design is not without difficulties. It involves the following three new problems that must be solved before it can be used.

1. A locomotive boiler is originally built as one rigid unit. If it is now to be divided into two sections, its rigidity might be impaired by the change in distribution of weight on the chassis of the locomotive and on the axles of the driving wheels.

2. The temperature of the middle section will be much higher than that of the conventional smokebox; hence the shell [of the forward section of the boiler?] must have suitable protection or else it will easily be burned out.

3. In the conventional design, the main steam header of the superheater and the multiple-valve throttle, through which the superheated steam enters the steam chests and cylinders, are in the smokebox. If the superheater is moved to the middle section of the boiler, how are the main steam header and multiple-valve throttle to be arranged?

For the solution of these three problems, I suggest using the design described below, whereby several other advantages may also be gained.

The boiler shell should still be one unit, with no impairment of its rigid construction, but with space in the middle section, to be called the superheater chamber, reserved for the installation of the superheater. This chamber should have a floor plate, similar to the roof of the firebox, but in an inverted position, and anchored with stay bolts. At the front and rear ends of the superheater chamber, there should be tube sheets divided into upper and lower sections, to permit the placing of stay bolts or angle braces. The upper portions of the tube sheets should be installed first. The tube sheets should be of the same size and shape as the tube sheet adjacent to the firebox. The lower portions of the tube sheets should be installed last, but an opening, with a tight steel plate cover, should be provided in the floor of the superheater chamber, to permit the removal of cinders.

In the shell of the boiler and at the top of the superheater chamber, a large hole should be made through which the superheater may be placed in position, firmly supported to prevent any motion, longitudinally or laterally. The rearward tube sheet should have three holes in its upper portion: a center hole for the main steam pipe to connect with the superheater, and a hole on each side for the steam pipes that connect the forward and rearward sections of the boiler. The forward tube sheet should also have three holes, the center one hole being for a large fire flue leading directly forward to the smokebox. In

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this large fire flue, the main superheated steam pipe should pass to the multiple-valve throttle. Finally, a cover should be installed to close tightly the opening through which the superheater was inserted. This design provides the following features:

1. There is no change in the rigidity of the boiler's structure. The extra floor plate will compensate for the hole at the top where the superheater is inserted.

2. The shell of the boiler is protected by the extra floor plate, with water circulating between.

3. There is good circulation of water and steam from front to back and up and down, just as with two boilers functioning in parallel.

4. The arrangements for cleaning out the boiler are the same as in the conventional design. Water scale can also be removed as in the past from underneath the firebox.

5. The cinders that collect in the superheater chamber can be removed through a hole at the bottom. Since the chamber is conveniently arranged, a smokebox netting can be dispensed with, without danger of fire from sparks or burning cinders.

6. Installation of the additional tube sheets for the superheater chamber, servicing the apparatus, and repairs are all being easily done.

7. If the cover plate above the superheater burns out, it can easily be changed, and is not a serious problem.

8. There is no objectionable increase in boiler weight. The tubes that were in the space now used for the superheater are dispensed with, as is the water that surrounded those tubes. Since the superheater itself is comparatively light, much weight is saved. Hence, although a few pieces of plate and two tube sheets have been added, the total weight of the newly designed boiler is about the same as that of the conventional boiler.

9. The space in the smokebox formerly occupied by the main steam header from the superheater is about 0.6 [cubic] meter; it can be used for some other purpose.

These nine features dispose of the first two of the three problems mentioned previously. The third problem is solved as follows.

After the burning gases have passed through the superheater, their temperature should be about 600 degrees centigrade, and they can flow onward by either of two passages. One of these is through the small fire tubes of the forward section of the boiler where their heat will be largely absorbed, so that their temperature will drop to about 200 degrees centigrade, and then they will pass out through the smokebox and the smokestack. The other passage for the gases is through a large flue in the upper portion of the forward section of the boiler. When in this flue, which is also occupied partly by the superheater's main steam header, the gases are surrounded by saturated steam. The area of cross section of the flue should be designed so that, when the gases reach the smokebox, their temperature will be about 400 degrees centigrade. Then they should pass through the arrangement for preheating the cold air, where they will give up enough heat to bring their temperature down to about 200 degrees centigrade, and then pass out through the smokestack. The cold air that has thus been preheated is led backward to the place where it is sprayed into the firebox in order to bring its temperature up to a high point and assure complete combustion of the fuel.

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The fire tubes of a large locomotive boiler are usually 6-7 meters long. If the length of the superheater chamber, from front to back, is subtracted from this length, the remaining length of the fire tubes should be divided into two sections, part in the forward section of the boiler and part in the rearward section. How much of the length should be in each section should be determined by the way it is desired to regulate the temperature of the burning gases as they pass from the combustion chamber to the smokebox. If there is difficulty on this score, the diameter of some of the small fire tubes can be increased or decreased, with corresponding changes in the space between the tubes.

The multiple-valve throttle should still be placed in the upper part of the smokebox as close as possible to the superheater's main steam header. There should be a cover in the upper part of the smokebox that can be opened and closed as needed, so that it will be easy to inspect and repair the throttle.

C. Discussion of the New Design

1. To deal with the need for changes in the fire tubes of the rear section of the boiler, the diameter of the fire tubes in the forward section can be increased, so that the rear-section tubes can pass through them. Although this arrangement decreases the evaporating capacity of the forward section, the length of the rear section and of the superheater chamber is not reduced; and the problem of design is easy to solve.

2. When making design calculations, a higher figure than is customary in the case of conventional boilers should be taken for the evaporating capacity of the fire tubes in the rear section, because the tubes themselves are thinner than in common practice. Also, a lower figure for the evaporating capacity of the fire tubes in the forward section should be taken, because the temperature of the burning gases in them will be lower than ordinarily. However, the thinner tubes in the rear section compensate for part of the loss in the forward section. On the whole, the heating surface of the fire tubes in the new type of boiler should be 20-30 percent greater than in the old type; and the evaporating capacity should be increased by 10-20 percent.

3. The main points in the regulation of temperatures in the boiler are best shown by means of the following figure.

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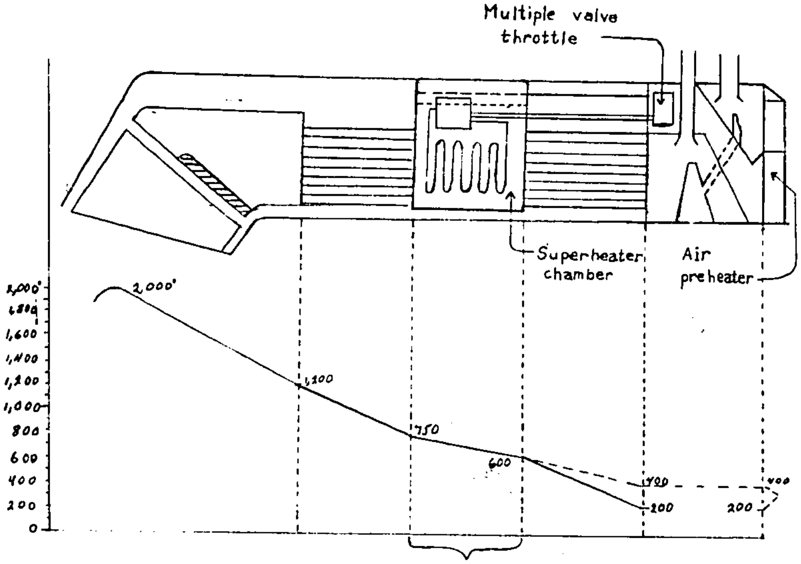
Figure 2



Based on estimated 150° drop in temperature of burning gases, and use of 140° of superheat of the steam

4. After the admission of preheated air needed for combustion, the temperature in the firebox is certainly high, and its function there is to increase the evaporation rate. The objection to this high temperature is that it may fuse the cinders into masses of vitreous slag. For this reason, the coal used as fuel should be carefully selected, particularly as to its ash content, so that the formation of vitreous slag can be avoided. As for the design of the grate, it is best to use the rocking-bar type so that the supply of cold air may be regulated.

5. Various advantages of the new design

a. If the temperature of the gases in the smokebox is reduced by one half, about 7 percent of the heat may be recovered instead of wasted, but some of that is used by the blower mechanism.

b. The preheating of the air contributes to more complete combustion, and makes possible the recovery of about 2 percent of the heat. These two together about equal the total heat capacity of the cylinders.

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c. The degree of superheating can be controlled at a higher steady temperature, limited by its effect on the lubrication of the cylinders. The pressure coefficient can be raised, which increases the locomotive's tractive power.

d. The heating surface of the boiler can be increased 20-30 percent; evaporating capacity increased 10-20 percent; the locomotive's horsepower and speed can be increased.

e. Since the superheater is compact, it is convenient and comparatively inexpensive to construct, inspect, and repair.

f. The total weight of the boiler can be reduced.

g. The cinders are retained in the bottom of the superheater chamber, so they do not escape through the smokestack; hence the danger from sparks is reduced, and the wire net in the smokebox can be eliminated. (With a preheater for the cold air assuring more complete combustion, the quantity of cinders is reduced to a minimum.)

h. The design of this type of boiler is simple and easy. The boiler's unit evaporating capacity depends mostly on the size of the firebox; hence it has always been the practice in the design of larger locomotives to enlarge the firebox and lengthen the combustion chamber. In the design of the new type of boiler, the main consideration will still be to provide a firebox with a large evaporating capacity. But the fire-tube sections are not of the same size nor of the same evaporating capacity; that of the forward section is much less than that of the rear section. The designer must determine the comparative lengths of the front and rear sections in the proportion that will make the boiler most efficient in supplying steam to the cylinders.

6. To evaluate the above designs and estimates, the writer compared the characteristics of the new type of boiler with those of a conventional boiler of a Pacific-type locomotive. His findings are shown in the following table.

Characteristics of Old- and New-Type Boilers

Type of Boilers	Heating Surfact in Sq Ft (excluding firebox)	Evaporating Capacity in Pounds per Hour (excluding firebox)		Cross-Section Area of Tubes (sq in)	Weight of Boiler *
Old	1,423.6	15,048		690	100%
New design	Rear sec, 966	Rear sec (evap coef, 14.2)	13,617	Rear sec, 724; fwd sec, 650	114%
	Mid, sec, 64	Mid sec (evap coef, 6.0)	384		
	Fwd sec, 648	Fwd sec (evap coef, 6.0)	3,888		
	Total, 1,678				
		Total	17,889.2		

(Average evaporation coefficient, 11.0)

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NOTES: i. Since the temperature in the smokebox is lowered, the volume of gases and smoke in the smokebox is smaller. Although the area of cross section of the fire tubes in the forward section is less, this is not objectionable.

ii. No figures are available for ascertaining the evaporating capacity with tubes 6 feet long; hence in these calculations, I have used a figure read from graphs of previous tests where I extended the curves. The figure thus derived for the combined capacity of the forward and rear sections does not exceed what is already known from experience, and hence this device does not invalidate my calculations.

* Excluding the hot air installation and the parts where no change in design was made

7. Increase in heating efficiency. This is attributable to some degree to the lower temperature in the smokebox; to a smaller degree to the use of a preheater for combustion chamber air; but most of all to the placing of the superheater in the middle section of the boiler. Otherwise, the other two advantages would be impossible.

8. Actual tests should be made to ascertain the practicability of the new design. In the tests, the following points should be investigated:

a. Whether the graduated lowering of the temperature in the different sections of the boiler, as shown in the Figure 2, is appropriate, and whether the method of regulating the temperatures is satisfactory.

b. The durability of the cover above the superheater. Can the temperature of the smokebox be lowered still more without affecting the superheated steam?

c. The efficacy of the cold air heater. How much can the temperature in the firebox and combustion chamber be raised by the preheating process? Does the ash in the coal create difficulties?

9. The principles of this new design have been discussed with a number of close friends, but the circle of consultants is too limited. The writer hopes that readers of this article will frankly point out its errors and remedy its deficiencies.

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